

# ROSAT X-ray luminosity functions of the Hyades dK and dM stars

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## ABSTRACT

A programme of long-duration ( $\sim 20$ – $40$  ks), *ROSAT* PSPC pointed observations of the Hyades open star cluster has been conducted. So far, 11 fields have been analysed, yielding, for selected regions (total area  $\sim 3.5$  deg<sup>2</sup>), a sensitivity improvement over the PSPC all-sky survey of more than a factor of 5, and providing high-quality spectra and time series for the brighter sources. Approximately 75 per cent of the Hyads within the fields are detected in X-rays, including 23 out of 32 dM stars and 13 out of 17 dK stars; this allows us to construct their X-ray luminosity functions (XLFs) down to  $L_X \sim 5 \times 10^{27}$  erg s<sup>-1</sup> (0.1–2.4 keV). All four dMs with  $M_V > 13$  in our sample have been detected. We compare the Hyades dK and dM XLFs from our observations with published *Einstein* dK/dM XLFs. The Hyades dK binaries have significantly higher  $L_X$  than the Hyades dK single stars. However, all these binaries have relatively long periods ( $\geq 1$  yr), and hence the high  $L_X$  levels cannot be attributed to the enhanced activity expected in short-period ( $\leq$  few days), ‘BY Dra-type’ systems. We also show that the effect cannot be due simply to the summed luminosities of the component stars. We discuss possible explanations in terms of pre-main-sequence evolution.

**Key words:** stars: activity – binaries: general – stars: coronae – stars: low-mass, brown dwarfs – open clusters and associations: individual: Hyades – X-rays: stars.

## 1 INTRODUCTION

Apart from the very extended UMa cluster, the Hyades is the nearest open star cluster to the Sun, at a distance of about 45 pc. Its age is  $\sim 7 \times 10^8$  yr, and it contains  $> 400$  known members extended over  $\sim 40^\circ$  diameter on the sky (e.g. Griffin et al. 1988; Reid 1992, and references therein). The proximity of the Hyades to the Sun allows the detection of relatively low-luminosity sources, with little absorption of low-energy X-rays. The first X-ray observations were made with the *Einstein Observatory* over 10 yr ago, mainly within a few degrees of the cluster centre. *Einstein* detected 66 members (out of 121 in the *Einstein* IPC fields) (Stern et al. 1981; Micela et al. 1988), allowing a good determination of the F- and G-type stellar X-ray luminosity functions. Recently, the *ROSAT* all-sky survey has provided an unbiased mapping of the whole cluster; 108 Hyads were detected in a preliminary analysis (Stern et al. 1992), and  $> 180$  in a subsequent, more detailed investigation (Stern, Schmitt & Kahabka, in preparation).

However, long-duration, pointed *ROSAT* observations are needed to study the X-ray-faint members, especially at

spectral types K–M. We have been conducting such a programme of deep exposures, and in this paper we present the X-ray luminosity functions (XLFs) of the Hyades dK and dM stars, derived from analysis of 11 pointings performed over the period 1991 February to 1993 February. We also discuss the detection of several of the lowest mass Hyads ( $M \leq 0.3 M_\odot$ ).

## 2 THE OPTICAL CATALOGUE

We obtained our input catalogue of Hyades stars using, for the most part, references from the published literature (see Stern et al. 1992). We were rather liberal in our *initial* criteria for Hyades membership, preferring to retain stars deemed either probable or, in some cases, possible members, in order to test them for detectable X-ray emission. In all, our preliminary Hyades input catalogue contains  $\approx 450$  members with  $m_V \leq 16$ . We estimate that fewer than 5–10 per cent of the catalogue stars are likely to be non-members.

For the purposes of deriving the XLFs, we have defined the samples from our input catalogue as follows.

(i) **dM stars:**  $m_1 \geq 12.0$ , plus VA 334 ( $m_1 = 11.65$ , on the basis of  $R - I = 0.75$ ), but excluding the white dwarf (WD) star VA 292. The WD + dM5e binary VA 673 (= HZ 9) was *not* excluded, since there is strong evidence that the dM star dominates the X-ray emission [the WD is too cool at  $T_{\text{eff}} \approx 15\,600$  K (Kidder 1991), and our X-ray spectrum is characteristic of that expected from a coronal source rather than the very 'soft' emission from a hot WD (Pye et al., in preparation)]. Using instead a criterion of  $B - V \geq 1.45$ , the sample would be changed by only 2–3 stars, and this would not significantly affect the XLF.

(ii) **dK stars:**  $B - V \geq 0.8$  and  $m_1 < 12.0$ , but excluding VA 334 (taken as a dM) and, of course, the Hyades giant-K stars.

Stars were only included in the *final* samples if their Hyades membership probability according to Hanson (1975) was  $\geq 50$  per cent or there was good evidence for membership from other sources (e.g. Griffin et al. 1988; Reid 1993). The resulting dK and dM Hyad samples are listed in Table 1 and contain 17 and 32 entries, respectively. Six of the dKs and five of the dMs are known or suspected binary systems. However, while there are estimates of (or at least bounds on) the periods for five of the dK stars, the only dM with a measured period (0.56 d, Lanning & Pesch 1981) is the spectroscopic binary VA 673. For completeness, we list, in Table 2, those dK–dM stars in our input catalogue that were finally excluded from the analysis on the grounds of poor membership qualifications.

### 3 OBSERVATIONS AND DATA ANALYSIS

The observations were performed with the *ROSAT* (Trümper et al. 1991) X-ray telescope (XRT) with the position-sensitive proportional counter (PSPC, Pfeffermann et al. 1986) at the focus. 11 separate pointings have been acquired in the central region of the Hyades; some have separations of less than one degree on the sky, and hence the PSPC fields overlap in these cases. The observations were made during the periods 1991 February 24 to March 7 (five fields), 1991 August 30 to 31 (two fields), 1992 September 10 to 12 (one field), 1993 February 23 to 27 (three fields). The nominal, planned exposure for nine of the fields (sequence numbers 200441–4, 200776–7, 201368–70; Pye et al., in preparation) was 20 ks each, the exceptions being a 40-ks exposure (sequence no. 200020; Stern et al. 1994), and a 5-ks exposure (sequence no. 200775; Pye et al., in preparation). The final exposure times achieved, taking account of data losses due to various effects (primarily periods of high background or poor aspect quality), were within  $\approx 20$  per cent of planned values for all except one field (no. 200441), where the net useful time was 8 ks.

Details of the data analysis are given in Stern et al. (1994) and Pye et al. (in preparation). In order to search for X-ray sources, the data for each observation (field) were binned into a sky image of  $512 \times 512$  pixel centred on the nominal pointing direction, each pixel being  $15 \times 15$  arcsec<sup>2</sup> (hence each image covered the full PSPC field of approximately 1 deg radius). For each data set the 'standard' TOTAL energy band was used, corresponding to a photon energy range of about 0.1–2.4 keV. The source-detection process<sup>1</sup> used a

<sup>1</sup>This used the program *pss* (version 1.6-1) in the UK Starlink ASTERIX X-ray data analysis package.

maximum-likelihood-ratio statistic (Cash 1979) to fit the spatially varying PSPC point-spread function to the data image and to test the significance at any point (Allan, Ponman & Jeffries, in preparation). For each local maximum in the significance map, where the value exceeded a specified threshold (here nominally corresponding to  $3.0\sigma$ , or a probability of  $\leq 0.3$  per cent that the detection is due to Poisson noise in the background), the best-fitting values of detected counts and position, and associated error ranges, were evaluated. The resulting list of X-ray source positions was cross-correlated against our Hyades star catalogue, taking a maximum separation of  $\approx 1$  arcmin as a match (see discussion in Stern et al. 1994).<sup>2</sup> Where a given Hyad was detected in more than one PSPC field, the X-ray detection with the highest significance was generally used (in most cases this was also the detection at the smallest off-axis angle, since detection sensitivity falls off towards the edge of the PSPC fields due to vignetting and increased width of the point-spread function). For Hyads falling within our PSPC fields but not detected, we have computed<sup>3</sup> upper limit counts at 99 per cent confidence, using the optical catalogue positions.

We considered only objects within  $\approx 50$  arcmin of each PSPC field centre, in order to avoid problems with the rapid fall in effective area at greater angles. The total area of sky surveyed by the 11 fields was about  $18 \text{ deg}^2$ , after allowing for overlaps. Approximately 75 per cent of the Hyads within the fields were detected, including 23 out of 32 dM stars and 13 out of 17 dK stars.

PSPC photon counts were corrected to 'on-axis' count rates, using the 'Standard Analysis Software System' (SASS) exposure maps. The fluxes and hence luminosities (Table 1) were derived using a conversion factor of 1 PSPC count  $\text{s}^{-1} = 6 \times 10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1} = 1.45 \times 10^{30} \text{ erg s}^{-1}$  (over the energy range 0.1–2.4 keV, and assuming a common distance of 45 pc for all cluster members). The minimum detected X-ray luminosity,  $L_X$ , is  $\approx 5 \times 10^{27} \text{ erg s}^{-1}$  (for VA 203,  $m_1 = 16.6$ , and for VA 321,  $m_1 = 15.0$ ). The upper limits (at 99 per cent confidence) range from  $\sim 4 \times 10^{27}$  to  $\sim 10^{29} \text{ erg s}^{-1}$ . Fig. 1 shows detected X-ray luminosities as a function of  $R - I$  colour, together with upper limit luminosities for non-detections.

### 4 X-RAY LUMINOSITY FUNCTIONS

With our sample of 32 Hyades dM stars, we have constructed an XLF using 'survival analysis' methods [specifically the Kaplan–Meier Product Limit Estimator (KMPL)] to take account of the upper limits (Feigelson & Nelson 1985, as implemented in the *ASURV* package version 1.2). The resulting cumulative luminosity distribution function is shown in Fig. 2(a). In a similar manner, we have constructed an XLF from our sample of 17 dK-star Hyads. For the dK Hyads, there is more information available on binarity (Griffin et al. 1988). All six known/suspected binaries are X-ray-detected, and these 'dK binaries' are all more X-ray-

<sup>2</sup>The alternative approach, of performing the maximum-likelihood fit at the locations specified by the Hyades optical catalogue, i.e. simply evaluating the best-fitting counts (and associated errors), yielded source counts differing by  $\leq 10$  per cent from the method used here.

<sup>3</sup>We used *pss* (version 1.7-0).

**Table 1.** dK-dM Hyads in the 11 *ROSAT* PSPC fields.

Designation <sup>(a)</sup> VA	H	$m_V$	Photometry <sup>(b)</sup> B-V	R-I	$L_X$ <sup>(c)</sup>	$\sigma(L_X)$ <sup>(d)</sup>	Notes
<i>dK sample:</i>							
133	185	9.60	0.99	0.32	3.79	0.62	$v=4.4$ <sup>(e)</sup>
135	187	10.02	1.09	0.48	16.31	0.68	binary <sup>(h)</sup>
146	192	12.00	1.45	0.71	< 2.27	0.00	
276	290	10.52	1.21	0.49	< 4.99	0.00	$v=3.2$ <sup>(e)</sup>
279	292	9.12	0.86	0.28	2.86	0.19	
294	299	10.90	1.29	0.52	1.70	0.31	
310	312	9.99	1.06	0.38	3.21	0.53	$v=4.1$ <sup>(e)</sup>
342	342	10.27	1.04	0.38	1.56	0.19	$v=5.0$ <sup>(e)</sup>
475	422	11.08	1.36	0.58	1.34	0.23	
500	441	10.70	1.31	0.60	30.23	1.04	$v=14.4$ <sup>(e)</sup> ; binary, $P > 5400$ <sup>(h)</sup>
502	442	12.00	1.42	0.71	< 1.19	0.00	
587	491	9.01	0.84	0.32	4.65	0.25	binary, $P=358.4$ <sup>(h)</sup>
622	505	11.85	1.44	0.72	< 0.72	0.00	
627	509	9.55	0.97	0.37	7.93	0.32	binary, $P=844.6$ <sup>(h)</sup>
645	517	11.05	1.28	0.52	1.53	0.26	
684	544	8.92	0.88	0.33	5.85	0.63	$v=6.7$ <sup>(e)</sup> ; binary, $P > 6000$ <sup>(h)</sup>
727	578	8.50	0.84	0.30	10.09	0.53	binary, $P \sim 5000$ <sup>(h)</sup>
<i>dM sample:</i>							
115	172	12.52	1.47	0.85	2.35	0.37	
118	173	15.11	1.57	1.25	< 1.71	0.00	
122	176	15.00	1.63	1.21	2.75	0.76	
127	181	16.15	1.63	1.31	< 7.97	0.00	
203	232	16.62	1.62	1.39	0.45	0.10	
213	242	15.44	1.55	1.33	3.09	0.37	
216	247	15.64	1.50	1.27	1.00	0.15	
242	266	13.00	1.52	0.95	2.13	0.56	
260	280	16.68	1.66	1.37	0.92	0.13	
262	284	15.82	1.77	1.31	< 3.54	0.00	
275	291	14.94	1.59	1.28	5.81	0.39	
282	294	14.76	1.59	1.16	< 1.10	0.00	
288	296	13.30	1.55	1.17	13.35	0.29	$v \sin i = 13.5$ <sup>(f)</sup> , binary <sup>(h)</sup>
297	300	12.55	1.47	0.81	< 0.36	0.00	$v \sin i < 10$ <sup>(f)</sup>
321	321	14.98	1.58	1.21	0.54	0.13	
334	336	11.68	1.43	0.75	24.63	0.50	binary <sup>(h)</sup>
351	346	13.21	1.53	1.20	22.42	0.61	$v \sin i \sim 10$ <sup>(f)</sup> , binary? <sup>(i)</sup>
352	348	16.37	1.66	1.33	1.62	0.19	
362	360	15.32	1.49	1.39	1.21	0.39	
368	366	16.25	1.58	1.34	0.68	0.07	
382	376	15.11	1.52	1.40	3.38	0.23	
383	378	12.19	1.44	0.74	3.49	0.16	
420	401	13.05	1.48	0.90	< 0.60	0.00	$v \sin i < 10$ <sup>(f)</sup>
512	449	14.26	1.53	1.15	< 14.08	0.00	
529	456	12.34	1.46	0.75	< 1.49	0.00	
575	484	14.45	1.55	1.21	4.02	0.29	
637	513	12.23	1.47	0.79	5.12	0.66	
638	514	12.17	1.46	0.78	1.60	0.26	binary <sup>(i)</sup>
657	521	15.23	1.57	1.24	1.23	0.13	
673	528	13.88	0.31	0.99	6.52	0.27	binary, $P = 0.56$ <sup>(g)</sup>
674	530	15.45	1.55	1.23	3.04	0.27	
731	581	12.33	1.44	0.68	< 0.85	0.00	

<sup>(a)</sup>VA: van Altena (1969); H: Hanson (1975).<sup>(b)</sup>See references in Stern et al. (1992); also Stauffer (1982).  $R-I$  values are on the Kron system.<sup>(c)</sup>X-ray luminosity ( $10^{28}$  erg s<sup>-1</sup>, in photon energy band 0.1–2.4 keV) computed from the *ROSAT* PSPC count rates, assuming a common distance of 45 pc for all the stars.<sup>(d)</sup>Error on  $L_X$ , computed from the standard deviation on the PSPC count rates due to counting statistics.<sup>(e)</sup>Radick et al. (1987).<sup>(f)</sup>Stauffer et al. (1987).<sup>(g)</sup>DA white dwarf + dwarf M, spectroscopic binary (VA 673 = HZ 9), period = 0.56 d (Lanning & Pesch 1981).<sup>(h)</sup>Binary period  $P$  (d) (Griffin et al. 1988; Batten et al. 1989). Stars without a quoted period have been designated as photometric and/or radial-velocity binaries in the literature (Bettis 1975; Carney 1982; Stauffer 1982; Griffin et al. 1988).<sup>(i)</sup>Visual binary with LP 415-175, separation  $\sim 4$  arcsec (van Altena 1969; Reid 1993).<sup>(j)</sup>Suspected spectroscopic binary or triple system (Latham & Stauffer, private communication).

Table 2. Possible dK–dM Hyads excluded from the analysis.

Designation <sup>(a)</sup>		Photometry <sup>(b)</sup>		$L_X$ <sup>(c)</sup>	$\sigma(L_X)$ <sup>(d)</sup>	Membership Probability <sup>(e)</sup>	Notes
VA	H	$m_V$	B–V				
	196	16.27	1.74	< 1.18	0.00	0	
	495	16.32	1.97	1.15	0.24	0	
125	180	11.25	1.29	< 0.71	0.00	0	
LP 414–158		16.09	–9.00	< 0.82	0.00	–	
191	220	12.16	1.08	< 0.13	0.00	0	
LP 415–543		15.34	1.76	1.50	0.24	–	
200	229	13.85	1.58	2.51	0.33	0	
GH 7–178	264	14.64	0.84	3.91	0.21	0	
241	265	14.89	1.73	< 0.46	0.00	21	Reid (1992, 1993)
265	285	15.90	1.48	< 0.50	0.00	76	Weis & Uggren (1982), Reid (1993)
305	303	15.11	1.74	4.52	0.17	0	
306	304	14.58	1.64	< 0.11	0.00	2	
329	330	14.81	1.60	< 0.17	0.00	21	Reid (1993) prob.=1%
366	363	12.38	1.45	5.67	0.38	30	rejected by Griffin et al. (1988)
380	374	13.73	0.87	< 0.22	0.00	2	
478	423	15.38	1.09	< 0.32	0.00	7	
578	485	10.76	0.87	< 0.30	0.00	3	
	588	7.22	1.13	< 0.24	0.00	2	
750	601	12.41	1.45	12.10	0.84	0	

<sup>(a)</sup>VA: van Altena (1969); H: Hanson (1975).

<sup>(b)</sup>See references in Stern et al. (1992); also Stauffer (1982).

<sup>(c)</sup>X-ray luminosity ( $10^{28}$  erg s<sup>–1</sup>, in photon energy band 0.1–2.4 keV) computed from the *ROSAT* PSPC count rates, assuming a common distance of 45 pc for all the stars.

<sup>(d)</sup>Error on  $L_X$ , computed from the standard deviation on the PSPC count rates due to counting statistics.

<sup>(e)</sup>Hanson (1975).

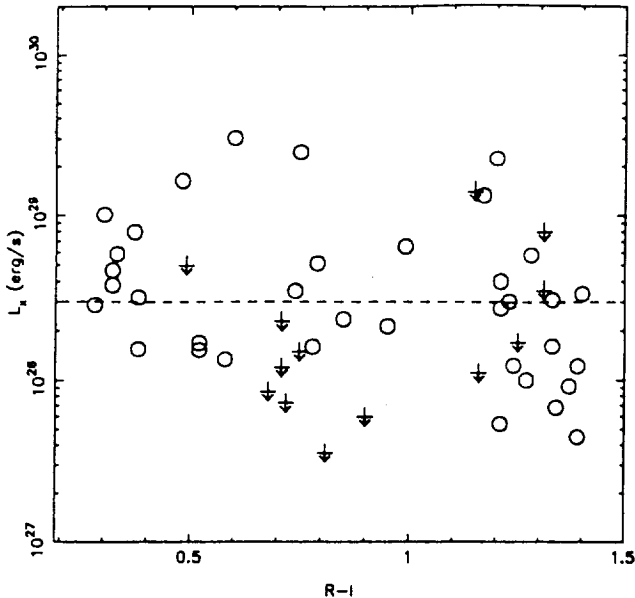
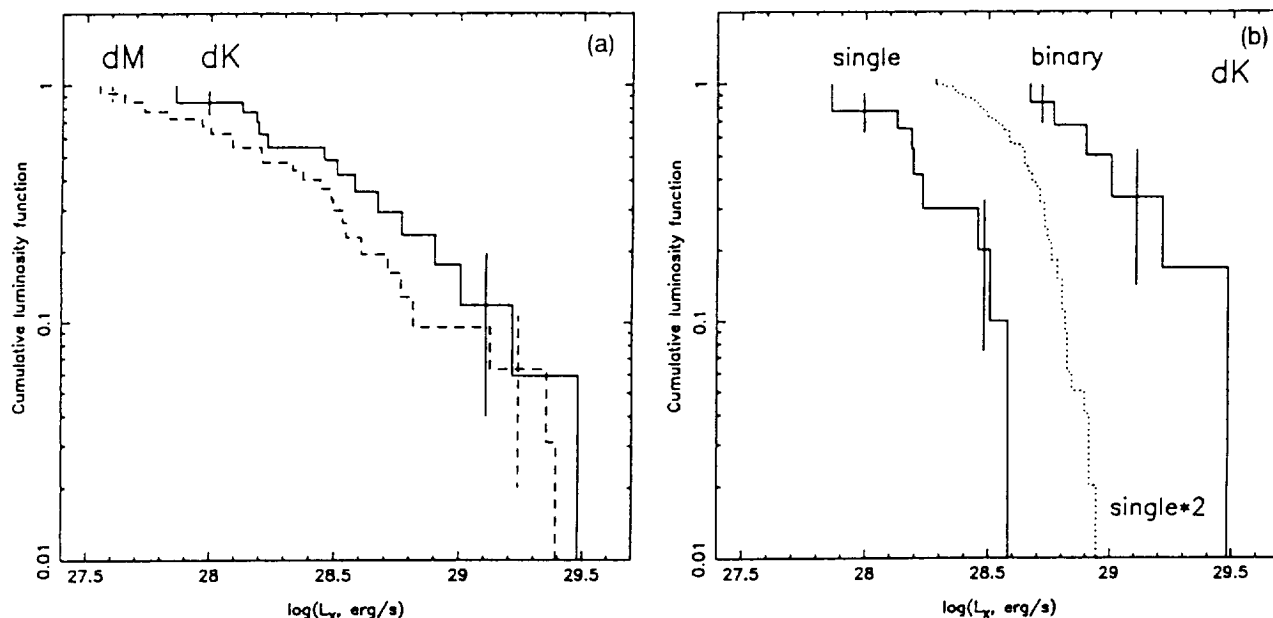


Figure 1. X-ray luminosity versus  $R-I$  colour for the dK and dM Hyads in our sample. Detections are indicated by circles ( $\circ$ ) and 99 per cent confidence upper limits by arrows ( $\downarrow$ ). A common distance of 45 pc has been assumed for all stars. The  $1\sigma$  statistical errors for the detections range from about 20 per cent for the weakest detections to 2 per cent for the strongest. The approximate *ROSAT* all-sky survey limit (Stern et al. 1992) is shown as a horizontal dashed line.

luminous than any of the other dK stars (the latter will be designated as ‘dK singles’, with 7 detections + 4 upper limits). The dK XLFs for the total sample, the binaries and the singles are shown in Figs 2(a) and (b). Table 3 summarizes the mean, median and interquartile values for the XLFs derived here. When compared over similar  $L_X$  ranges (i.e.  $\geq 3 \times 10^{28}$  erg s<sup>–1</sup>), the *ROSAT* and *Einstein* distributions are in good agreement (cf. Fig. 3).

In our sample of 32 dM stars, there are only five known or suspected binaries (VA 288, VA 334, VA 351, VA 638 and VA 673); all of them are X-ray detections, and four (VA 288, VA 334, VA 351 and VA 673) are amongst the most X-ray luminous in our dM sample (cf. Table 1). VA 638 is a visual binary (with LP415–175), with a separation  $\sim 4$  arcsec (van Altena 1969; Reid 1993), and does not exhibit an exceptional X-ray luminosity. There are insufficient objects to construct a separate, useful, dM-binary XLF. The lack of known dM binaries is likely to be simply an observational selection effect (see, e.g., Reid 1993), and comparison with the dK sample supports the suggestion (Stauffer 1982) that binaries may be strongly influencing the derived XLF. We defer further discussion of the possible influence of binarity on activity levels to Section 5.

Examination of the XLFs (Fig. 2) shows apparent ‘features’ on various luminosity scales, from changes in overall slope to much higher frequency variations. In order to investigate the reality or otherwise of these effects (i.e. the stability of the KMPLE solution) we have generated a



**Figure 2.** Cumulative X-ray luminosity distribution functions for the Hyades stars. (a) dM stars and dK stars; (b) dK-binary stars, dK-single stars, and the convolution of the dK-single-star distribution with itself ('single\*2'). The vertical error bars are as computed by the ASURV Kaplan-Meier Product Limit Estimator (Feigelson & Nelson 1985). A representative error bar is shown near each end of each luminosity function. However, since the distributions are cumulative, the error bars on each one will not be independent.

**Table 3.** Hyades dK-dM star X-ray luminosity functions.

Sample	No. of detections / Total no. in sample	log( $L_X$ , erg s <sup>-1</sup> )			
		Mean	Median	75th percentile	25th percentile
dM	23/32	28.26 ± 0.09	28.21	27.78	28.54
dK	13/17	28.49 ± 0.11	28.41	28.15	28.74
dK binary	6/6	29.01 ± 0.11	28.90	28.72	29.11
dK single	7/11	28.21 ± 0.08	28.19	27.90	28.34
dK+dM	36/49	28.33 ± 0.08	28.24	27.92	28.61

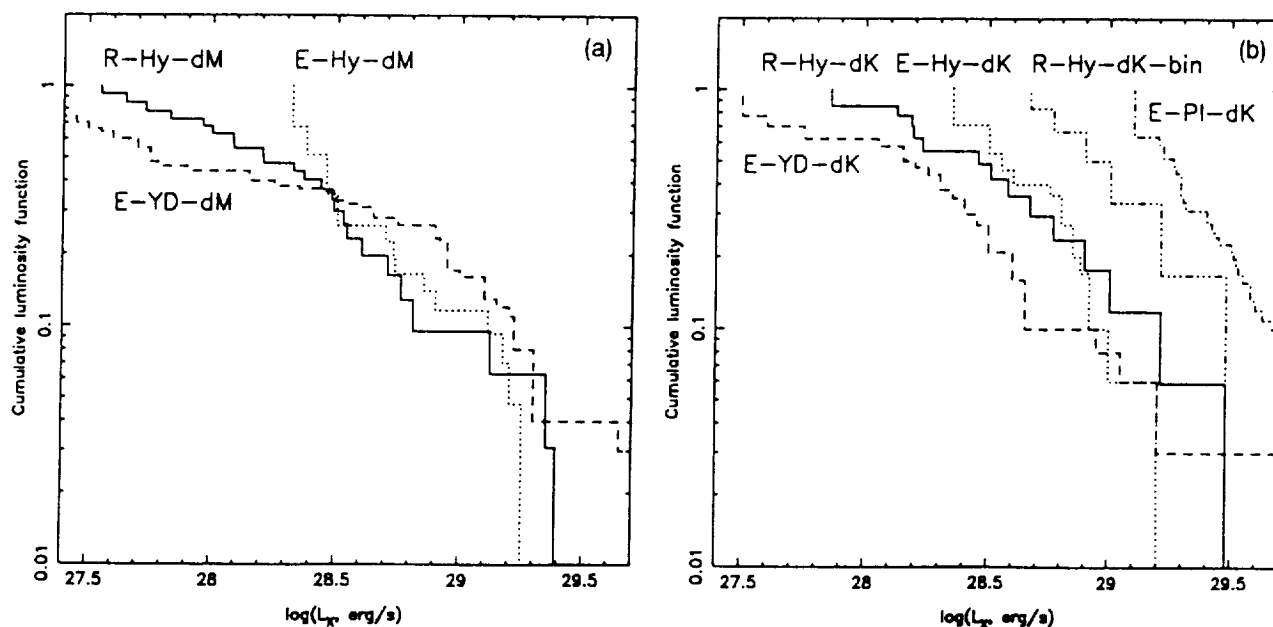
number of 'perturbed' data sets from the measured dM-star  $L_X$  values, and constructed the corresponding XLFs. The perturbations consisted of: (a) increasing and (b) decreasing all upper limits by a factor of 2; (c) removing all upper limits; (d) applying uniform random noise in the range  $\pm 0.18$  to  $\log L_X$  for all detections and upper limits, and making 10 different data sets in this manner. The resulting XLFs were compared with the original XLF both visually and by applying censored-data, two-sample tests (Feigelson & Nelson 1985).<sup>4</sup> It was found that: (i) the XLF was insensitive to the changes in the upper limits; (ii) the flattening of the dM-star XLF slope for  $L_X \leq 10^{28.3}$  erg s<sup>-1</sup> was reproduced from all our modified data sets; (iii) the reality of 'small-scale features'

over  $\Delta \log L_X \leq 0.5$  (e.g. localized changes in slope) should not be relied upon. In summary, the KMPLE XLFs that we have derived appear to be reliable within the calculated error estimates (as plotted in Fig. 2). Furthermore, the range of uncertainty applied in test (d) gives us confidence that the simplification of taking all Hyads at a constant distance (45 pc) has not significantly affected the XLFs.

## 5 DISCUSSION

Our *ROSAT* observations have allowed, for the first time, XLFs to be constructed for Hyades dK and dM stars down to  $L_X \sim 10^{27.7}$  erg s<sup>-1</sup>, with approximately 70–75 per cent of the sample stars being detected. An extension of the measured range of X-ray luminosities is important not only for studies of stellar activity in the Hyades cluster itself, but also in the wider context of comparisons with XLFs of other stellar samples such as nearby stars (e.g. Micela et al. 1988),

<sup>4</sup>We used ASURV version 1.2: Gehan's generalized Wilcoxon test – permutation variance, Gehan's generalized Wilcoxon test – hypergeometric variance, Logrank test, Peto & Peto generalized Wilcoxon test, Peto & Prentice generalized Wilcoxon test.



**Figure 3.** Comparison of the present *ROSAT* Hyades X-ray luminosity functions with various stellar X-ray luminosity functions derived from *Einstein* data (after Micela et al. 1988, 1990). (a) dM stars: *ROSAT* Hyades (R-Hy-dM), *Einstein* Hyades (E-Hy-dM), *Einstein* nearby-star young disc population (E-YD-dM); (b) dK stars: *ROSAT* Hyades (R-Hy-dK), *Einstein* Hyades (E-Hy-dK), *Einstein* nearby-star young disc population (E-YD-dK), *ROSAT* Hyades binaries (R-Hy-dK-bin), *Einstein* Pleiades (E-PI-dK). The *Einstein* Pleiades dK distribution has a high-luminosity tail extending off the right-hand side of the graph to approximately (30.0, 0.03) and (31.0, 0.01).

Galactic source count predictions (and hence stellar birthrate and evolution predictions, e.g. Micela, Sciortino & Favata 1993), and estimates of the contribution of stellar coronae to the Galactic X-ray background (e.g. Schmitt & Snowden 1990).

We can make a number of points by intercomparing our *ROSAT* XLFs and comparing them with published *Einstein* XLFs (cf. Figs 2 and 3).

(1) As already noted by Micela et al. (1988), for  $L_X \geq 10^{28.5}$  erg s $^{-1}$  the dM and possibly the dK XLFs for the Hyades and the nearby-star, 'young disc' population are very similar.

(2) The Hyades dK binaries have X-ray luminosities comparable to those of the Pleiades dK stars (binary + single; *Einstein*, Micela et al. 1990; *ROSAT*, Stauffer et al. 1993), with a formal probability of > 5 per cent that the XLFs are drawn from the same parent population.

(3) There is a low-luminosity component to the dK XLF, and this is dominated by single stars. The probability that the binary- and single-star XLFs are drawn from the same parent population is < 0.4 per cent.

(4) The *ROSAT*-derived dM and dK XLFs are similar, in that the ASURV two-sample tests all give probabilities of > 15 per cent that the two samples are drawn from the same parent population.

Returning to point (3) above, all the dK binaries in our sample have relatively long periods ( $\geq 1$  yr), and hence it is not immediately obvious why they should show such high activity levels. They cannot be attributed to the enhanced activity expected in short-period ( $\leq$  few days), 'BY Dra-type' systems, nor can they be due, in general, simply to the

summed luminosities of the multiple-component stars. This last point is demonstrated in Fig. 2(b), where we compare the dK single- and binary-star XLFs with one generated by convolving the dK single-star XLF with itself. The mean, median and interquartile ranges of the latter are [in  $\log(L_X, \text{erg s}^{-1})$ ] 28.62, 28.64, 28.49–28.74, respectively (cf. Table 3). We cannot offer a definitive explanation, but speculative ideas include: (i) the higher initial angular momentum available in the system; (ii) disruption of the accretion disc around the primary, by the secondary, during pre-main-sequence (PMS) evolution, thus removing a source of rotational braking (Königl 1991; Cameron & Campbell 1993). The latter suggestion may be supported by recently reported observations of rotation rates and occurrence rates in binaries of classical versus weak-lined (naked) T Tauri PMS stars, although the statistics are still provisional and in some cases conflicting, and require confirmation (Edwards et al. 1993; Ghez 1993).

Of particular interest for models of the convection zone and magnetic dynamo are indicators of coronal activity for the coolest stars, with very deep (or even fully) convective interiors (e.g. Cox, Shaviv & Hodson 1981; Liebert & Probst 1987; Dorman, Nelson & Chau 1989), i.e. those stars with mass  $\leq 0.3 M_\odot$ , roughly corresponding to spectral type  $\geq$  dM4,  $M_V \geq 12$ , or at the Hyades distance,  $m_V \geq 15.3$ . Fleming et al. (1993) have recently presented a study (using *ROSAT* PSPC all-sky survey results) of  $L_X$  as a function of  $M_V$  for a sample of nearby field dM stars with spectral types later than M5. Their results indicate that there does not appear to be a significant drop in X-ray activity at very late spectral types (contrary to some earlier studies based on more limited samples from *Einstein*). From Table 1, we see

that the *V*-band-faintest, X-ray-detected Hyads so far are VA 203 and VA 260, both at  $m_V \approx 16.6$ . The number of very low-mass Hyads so far available in our survey is rather small, and the greater distance will limit the Hyades sample to rather brighter objects (in both optical and X-ray bands); however, the high percentage of X-ray detections ( $\sim 70$  per cent both for  $12.0 \leq m_V < 15.0$  and for  $m_V \geq 15.0$ ) suggests that activity levels are maintained towards the latest spectral types in our sample.

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